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Economic Growth and Pollution Nexus in Mexico, Colombia, and Venezuela (G-3 Countries): The Role of Renewable Energy in Carbon Dioxide Emissions

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Abstract: The primary aspiration of this paper is to learn about the effects of economic growth (GDPG) and energy consumption (ENRC) on environmental pollution (EP) in G-3 countries and to show the significance of renewable energy consumption (RENEW) on environmental pollution (EP). The data covers the period from 1970 to 2020 by applying the “Pooled Mean Group-Autoregressive Distributed Lag” (PMG-ARDL) model. The results indicate that GDPG is negatively co-integrated with CO₂ emissions (pollution) in the short run (SR) but positively co-integrated in the long run (LR). Energy consumption has a positive impact in the long run, but there is no positive impact in the short run to accelerate pollution. In both the short and long run, renewable energy has a significant role in reducing environmental degradation. However, according to the Dumitrescu Hurlin panel, there was bidirectional causality (BC) involving energy consumption and pollution. Because of the large volume of energy emphasized in economic growth and development activities, energy use increases pollution. In addition, there was a BC involving energy consumption and economic growth. At the country level, a significant contribution implies sustainable development and the implication of environmental quality assurance policies.

Keywords: energy consumption; economic growth; environment; renewable energy; pollution; G-3 countries



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1. Introduction

Currently, economic growth largely depends on available energy. Environmental pollution has become a major concern in recent years as a result of increased energy consumption and economic activity. Carbon dioxide emissions (CO₂) are the principal cause of the greenhouse effect and are regarded as the world’s most serious environmental problem. Human survival becomes endangered due to these greenhouse effects [1]. The supply of energy is increasing day by day in order to strengthen the global economy, and as a result of the increased energy use, greenhouse gas emissions are increasing in the same direction, posing a major problem for the environment. To ensure sustainable development and growth, we must be concerned with environmental quality, which means environmental pollution. A sound and further developed economic sector has not just a solid commitment to improving the effectiveness of the economy but also a solid commitment to sustainable development. However, receiving these rewards from monetary advancement is not without environmental cost [2]. The opportunity cost of monetary or financial improvement began to plague people as pessimistic externalities and became more acute, especially since the late twentieth century, when the term “environmental or climate change” was coined in response to fears of a steady rise in the temperature of planet Earth. Unnatural climate change caused by CO₂ emissions is a widespread and complex issue in both developed and developing nations, and ecological sustainability has become a shared goal of every country.

However, Mexico, Colombia, and Venezuela signed a ten-year free-trade agreement, known as the Group of 3 (G-3 countries) that started in 1995 and went on until 2005. The agreement covered various issues, including rights of property, public-area ventures, and the facilitation of trade limitations. The G-3 did not keep going for a really long time, and Venezuela seemingly never turned into an exceptionally impressive member of the settlement. Nonetheless, the group of three prevailed with regards to helping exchanges between Mexico and Colombia. The group of three (G-3) supported the area's energy and utility areas, especially in oil, gas, and renewable energy. One of the G-3's most memorable ventures was connecting power frameworks and gas pipelines from Mexico to Colombia and Venezuela. However, the economic growth of Colombia was 7.7119%, and Mexico had negative economic growth in 2020, but the amount of energy consumption was 13,853.501 (primary energy consumption per capita, kWh/person). Venezuela had negative economic growth in 2020, but the amount of energy consumption was 18,808.4394 (primary energy consumption per capita, kWh/person). The carbon emission scenario was very impressive; the annual CO₂ emissions of Colombia were 74,489,415 t, Venezuela was 84,609,478 t, and Mexico was 356,968,119 t in 2020.

However, in these countries, the use of renewable energy has sharply increased. In 2020, the renewable energy consumption (% equivalent primary energy) of Colombia was 30.77%, Venezuela was 30.13%, and Mexico was 9.47%, which was the largest percentage of renewable energy consumption over the time period 1970–2020. Raising the trend of renewable energy helps reduce CO₂ emissions [3–5].

The purpose of this paper is to discern the impact of economic growth and energy utilization on environmental pollution in Mexico, Colombia, and Venezuela (the G-3 countries) and also measure the impact of RENEW on environmental pollution. We applied the “Pooled Mean Group-Autoregressive Distributed Lag” (PMG-ARDL) model and the Dumitrescu Hurlin panel, using data from 1970 to 2020. The G-3 countries are nations with abundant natural resources, are oil producers, and have been increasing the use of alternative sources of energy. The G-3 are large countries (especially Colombia and Mexico), growing rapidly in terms of economic activity during the last 50 years, and have regional leadership roles. The GDP of Mexico expanded from USD 35 billion in 1970 to nearly USD 1.1 Trillion in 2020. Venezuela and Colombia also expanded from less than USD 10 billion in 1970 to more than USD 480 billion and USD 315 billion, respectively, in 2020. In the last 50 years, electricity consumption per capita expanded more than 3.5 times in Mexico, and more than 2.2 times in Colombia and Venezuela and this scenario suggests the need to keep in mind the environment and ensure efficient distribution of environmental resources, which helps mitigate CO₂ emissions in the Latin American region. Because rising CO₂ emissions are a major provider to the threat of climate change, it is appropriate to look at the nexus involving GDPG and the environment to take proper measurement.

Specific objectives are the following: (a) to determine the sway of economic growth and energy consumption on environmental pollution; (b) to quantify how renewable energy reduces emissions; and (c) to reveal the long- and short-run impacts of the selected variables on the pollution in G-3 countries. This study contributes to the literature of energy studies in the context of Latin America as the result of the study aim at identifying which factors are more responsible for raising pollution and which factors require more attention to curb environmental pollution. Second, we contribute by assessing the economic growth trajectory and energy consumption of three important countries in Latin America: Colombia, Mexico, and Venezuela. Third, this study has important implications for energy policy in these developing countries. The three countries were or are major oil producers, so it offers a special interest considering the low incentives to transition from dirty to clean energy in oil- and gas-producing countries. Fourth, the study uses 50 years of data offering a more extensive data series than the vast majority of studies in Latin America. Finally, the study contributes to the literature of energy studies through the application of two methodologies, seldom applied, that are superior to more commonly used methods. We

apply the Pooled Mean Group-Autoregressive Distributed Lag (PMG-ARDL) model and the Dumitrescu Hurlin panel, which are used as robustness tests.

There are existing studies investigating the nexus between economic growth and CO₂ emission [6–9]. The research output shows different phenomena. Some studies found that economic growth has a positive impact on CO₂ emission [10–14]. On the other hand, some studies found that economic growth helps reduce carbon dioxide emissions as countries improve efficiency in the production, distribution, and consumption of energy [15–20]. However, more often studies support that energy use raises economic growth but increases CO₂ emissions [2,8,21–23], imposing an environmental burden on countries expanding rapidly. However, shifting to alternative sources of renewable energy has supported the reduction in CO₂ emission [1,24–29], offering an alternative solution to environmental degradation.

There are various papers (Table 1) on environmental pollution and the factors contributing to it, such as CO₂ emissions into the atmosphere. Many researchers have used variables such as GDPG and energy consumption to show the impact of environment pollution in several countries [13,30–35]. There was no comprehensive study of the liaison between GDPG and pollution in this panel group. However, this study contributes to the accumulation of the results and policies based on the findings of this panel group, which are largely found in the existing literature.

Table 1. Summary of Relevant Literature.

Authors	Country and Time	Method	Key Findings
Robalino-López et al. [36]	Venezuela; 1980–2025	EKC Hypothesis	GDP has positive impact on environment and exist in an inverted U-shape EKC.
Bilgili et al. [37]	OECD countries; 1977 to 2010	FMOLS, DOLS	GDP per capita raises CO ₂ emissions. RENEW reduces CO ₂ emissions.
Bhattacharya et al. [38]	Developed and Developing countries; 1991 to 2012	GMM, FMOLS approach	RENEW has both positive and negative impacts on GDPG and EP, respectively.
Charfeddine and Kahia [39]	MENA region; 1980 to 2015	PVAR model	RENEW and financial development have less influence on EP.
Zhang [40]	China	Econometric techniques	In China, financial development an important driver in increasing pollution.
Shahbaz et al. [41]	Malaysia; 1971 to 2008	Ng-Perron stationarity test	Financial development decreases pollution.
Ghorash and Rad [42]	Iran; 989 to 2016	PMG and MG Regression techniques	Financial development reduces CO ₂ emission.
Spetan [43]	Jordan; 1986 to 2012	ECM model	RENEW decreases CO ₂ emissions.
Shafiei [44]	OECD Countries; 1980 to 2011	DOLS approach	BC exists between GDPG and RENEW.
Strelesky and Lynchm [45]	169 countries; 1989 to 2003	Fixed effect regression	Exports are positively related to CO ₂ emission.
Cetin et al. [46]	Turkey; 1960 to 2013	The Lee and Strazicich test, VECM model	CO ₂ emission is determined by energy utilization.

Table 1. Cont.

Authors	Country and Time	Method	Key Findings
Zarzoso et al. [47]	European countries; 1975 to 1999	Econometric approach	Population growth raises CO ₂ emissions in EU members' countries.
Li and Su [48]	United States; 1990 to 2015	VAR model	Renewable energy reduces CO ₂ emissions.
Bosupeng [49]	37 countries; 1960 to 2010	Toda and Yamamoto causality approach	Exports reduce CO ₂ emissions.
Tiwari [50]	India; 1971 to 2007	VAR model	Energy consumption positively influences CO ₂ emissions and GDP.
Azam et al. [51]	China, Japan, USA, India; 1971 to 2013	FMOLS method	Carbon emissions and economic growth energy have negative relation.
Mesagan [52]	Nigeria; 1970 to 2013	Error correction model	Economic growth positively impacts carbon emission and trade openness, investment positively accelerates CO ₂ in Nigeria.
Arouri et al. [22]	North African and Middle East; 1981 to 2005	Co-integration techniques	GDPG accelerates EP positively.
Liu et al. [53]	Southeast Asia Nations; 1970 to 2013	EKC hypothesis	Renewable energy reduces CO ₂ emissions.
Kulionis [54]	Denmark; 1972–2012	VAR model	No causality exists with growth and CO ₂ emissions.
Jian et al. [55]	China, 1982 to 2017	VECM approach	FD and RE positively related with environmental pollution.
Udo et al. [56]	49 African countries; 1990 to 2010	Fixed-effects model	Urbanization lessens environmental effluence.
Fakhri et al. [57]	Mena Countries; 1990 to 2010	FMOLS, DOLS approach	Energy consumption positively increases CO ₂ emission.
Aye and Edoja [11]	Developing countries; 1971 to 2013	Panel regression	Economic growth and population swell CO ₂ emission.
Qi et al. [58]	China; 2010 to 2020	C-GEM model	Renewable energy reduces CO ₂ emissions.
Hasan [59]	Bangladesh; 2000 to 2016	VECM	CO ₂ emission increases more than GDP growth in Bangladesh.
Cheng et al. [60]	BRICS; 2000 to 2013	Quantile regression	The RENEW decreases and GDP per capita raises CO ₂ emissions.
Fan et al. [61]	Different income level countries; 1974 to 2014	STIRPAT model	The population has a negative shock on total carbon secretion.
Al-Mulali [62]	Biofuel energy consuming countries; 2000 to 2010	The panel data analyses	Bio-fuel energy reduces environmental pollution.

Table 1. Cont.

Authors	Country and Time	Method	Key Findings
Atici [63]	European countries; 1980 to 2002	Environmental Kuznets curve	Economic growth reduces CO ₂ emission and energy increases pollution in the region.
Mikayilov et al. [64]	Azerbaijan; 1992 to 2013	ARDL BT, DOLS, FMOLS, and CCR methods	Economic growth positively influenced CO ₂ emissions.
Cai et al. [65]	G7 countries	ARDL bound test	No co-integration exists among GDPG, ENRC, and EP.
Hanif [66]	Sub-Saharan Africa; 1995 to 2015	GMM method	The consumption of fossil and solid fuels of urban areas increases CO ₂ and the study also shows that renewable energy reduces environmental pollution.
Marques et al. [67]	Australia; 1965 to 2016	EKC, DI, ARDL, and VECM model	Economic growth raises carbon emissions and consequently pollutes the environment.
Cheng et al. [60]	BRIICS countries; 2000 to 2013	Quantile regression	The RE decreases CO ₂ emissions, GDP per capita raises CO ₂ emissions, exports increase carbon emissions here, FD enhances CO ₂ emissions per capita.
Boutabba [68]	India	Multivariate approach	There exist LR and causal relationships between per capita CO ₂ , ENRC, and FD.
Fan et al. [69]	Different countries, 1975 to 2000	STIRPAT model	The population has a negative shock on total carbon secretion.
Anser et al. [70]	SAARC; 1994 to 2013	STIRPAT model	Population and GDP are liable for high carbon release in the SAARC countries.
Patiño et al. [71]	Colombia; 1971–2016	Mean Divisia index method	Energy is a significant contributor for CO ₂ emission.
Salazar-Núñez et al. [72]	Mexico; 1973–2018	FMOLS	Economic growth largely affects CO ₂ in both the short and long run by considering EKC.

Source: Author's collection.

2. Methodology

2.1. Data and Sample

To conduct this research, data were collected from the World Development Indicator (2022) and International Energy Statistics (2022) for G-3 countries. Colombia, Venezuela, and Mexico were members of G-3 countries. A balanced panel of data was collected from the year 1970 to 2020.

2.2. Model Specification

The econometric model to estimate determinant factors of environmental pollution, uses Annual CO₂ emissions ton (CO₂) as a function of the following variables. Economic growth (GDPG) = GDP growth (annual %); renewable energy (Renew) = renewable en-

ergy (% equivalent primary energy); and energy consumption (Enrc) = primary energy consumption per capita (kWh/person).

$$CO_2 \text{ emissions} = f(\text{economic growth, energy consumption, renewable energy consumption}) \quad (1)$$

By taking natural logarithm of Equation (1) the final econometric model is,

$$\ln CO_{2,it} = \alpha + \beta_1 \ln GDP_{it} + \beta_2 \ln Enrc_{it} + \beta_3 \ln Renew_{it} + \mu_{it} \quad (2)$$

$$t = 1, 2, 3 \dots, T; i = 1, 2, 3, \dots, N \quad (3)$$

where i denote countries and t denotes time. N is the number of the countries. t is the model's observed time.

2.3. Empirical Methodology

2.3.1. Cross Sectional Dependency Test (CSD)

The CSD test is important to determine the dimension of panel analysis, either first-generation panel or second-generation panel. The most used method of cross-sectional dependency test is Pesaran's CD test. In this process, Pesaran's CD test considers the LM test as,

$$LM = T \sum_{i=1}^N \sum_{j=i+1}^N \hat{\rho}_{2ij} \quad (4)$$

where $\hat{\rho}_{ij}$ is the simple estimate of residual correlation. The hypothesis of this case has been developed as H_0 : there is no cross-section dependency.

2.3.2. Panel Unit Root Test

Some criteria are being used in panel unit root tests such as the "Im, Pesaran and Shin W-stat, ADF—Fisher Chi-square, PP—Fisher Chi-square, Levin, Lin & Chu t^* " method. However, due to the presence of cross-sectional dependence, the CIPS panel unit root test is more appropriate. The common estimation process of CIPS panel unit root is presented in Equation (4). The estimated null hypothesis (H_0) is that there is no stationary data series (with a unit root), whereas the alternative hypothesis H_1 is there is a stationary series (no unit root)

$$\Delta y_{it} = \delta_i + \beta_i y_{it-1} + \rho_i f_i + \epsilon_{it} \quad (5)$$

where the unit root has taken the hypothesis as H_0 : $\beta_i = 0$ for all i .

The recognized null hypothesis defines that there is no stationary series (unit root).

2.3.3. Cointegration Test

The cointegration equation can be presented in the following manner:

$$Z_{it} = \delta_i + \beta V_{it} + \epsilon_{it} \quad (6)$$

Here δ_i and β are the parameters and the residual term presented by ϵ_{it} Kao [73] suggests the cointegration technique with respect to the ADF test. The estimation process follows Equation (7)

$$\epsilon_{it} = \alpha \epsilon_{it-1} + \sum_{k=1}^m \theta_j \Delta \hat{\epsilon}_{i,t-j} + \epsilon_{it} \quad (7)$$

where the parameter of α and the residual term are uncorrelated. The hypothesis to test for cointegration is that H_0 : No co-integration relationship exists amongst the series. This study aimed to reject the H_0 (accepting the H_1).

2.4. PMG Panel ARDL

The panel ARDL approach was first introduced by Pesaran and Shin [74] and expanded by Pesaran et al. [75], dealing with the long- and short-run relationships among the

variables. Banerjee et al. [76] showed that the error correction term (ECT) can be derived from the ARDL approach. Furthermore, whether the data are integrated at level, first difference, or mixed order, the ARDL approach can be used to establish the continuation of a LR relationship among the variables. However, when the data series is stationary in mixed order, ARDL is the most useful method for estimating the results where “some variables are stationary at level I (0), while others are stationary at the first difference, I (1).” On the other hand, a CSD problem exists among the cross unit, due to presence of CSD and data stationary. At the level and 1st difference this study applied the PMG ARDL model. To achieve its objectives, the panel PMG ARDL econometric procedure is working on this investigation. There are some advantages such as the estimation of SR and LR coefficients and the estimation of the result of individual cross section units. The ARDL method has been applied in studies such as those from Osabohien et al. [77] and Arshad et al. [78], serving as reference to our study. The PMG ARDL prevalence stems from its ability to assess both the SR and LR affect and the cross-sectional short run of the logical factors on the investigation [79]. Among the many strengths of the model (PMG ARDL) is its aptness for examining a diverse order of dataset reconciliation (i.e., when datasets can be I (0), I (1), or a combination of both).

The stationarity tests in the current setting show that the dataset is I (0) and some are stationary at I (1), indicating the PMG panel ARDL approach [80]. This method was first introduced by Pesaran et al. [81]. The equation of panel ARDL model is:

$$\Delta \ln \text{CO}_{2it} = \beta_0 + \beta_1 \ln \text{GDPG}_{i,t-1} + \beta_2 \ln \text{Enrc}_{i,t-1} + \beta_3 \ln \text{Renew}_{i,t-1} + \sum_{j=1}^k \gamma_{1j} \Delta \ln \text{GDPG}_{i,t-j} + \sum_{j=0}^k \gamma_{2j} \Delta \ln \text{Enrc}_{i,t-j} + \sum_{j=0}^k \gamma_{3j} \Delta \ln \text{Renew}_{i,t-j} + \varepsilon_{it} \quad (8)$$

where Δ is first difference term, ε_{it} is the error term, and β_1 , β_2 , β_3 , and β_4 communicate to the long-run coefficients and the short run estimation showed by γ_{1j} , γ_{2j} , γ_{3j} , and γ_{4j} .

The long run equation is indicated in the following equation:

$$\Delta \ln \text{CO}_{2it} = \beta_0 + \beta_1 \ln \text{GDPG}_{i,t-1} + \beta_2 \ln \text{Enrc}_{i,t-1} + \beta_3 \ln \text{Renew}_{i,t-1} + \varepsilon_{it} \quad (9)$$

When the long-run association exists among the variable, then the error correction model has been performed. The equation of ECT is:

$$\Delta \ln \text{CO}_{2it} = \beta_0 + \sum_{j=1}^k \gamma_{1j} \Delta \ln \text{GDPG}_{i,t-j} + \sum_{j=0}^k \gamma_{2j} \Delta \ln \text{Enrc}_{i,t-j} + \sum_{j=0}^k \gamma_{3j} \Delta \ln \text{Renew}_{i,t-j} + \omega \text{ECT}_{i,t-1} + \varepsilon_{it} \quad (10)$$

where ω presents the lag of the next period which means the error correction term (ECT). The term ECT means the speed of adjustment for a disequilibrium situation to move an equilibrium situation. To establish a long-run alliance, the analysis must consider the ECT estimation in the econometric analysis.

2.5. Panel Causality Tests

The Dumitrescu Hurlin Panel Causality Test has been used in the case of the causal test when the data series has a cross-sectional dependence. Through this estimation, cross-sectional dependence has been applied to test the causality.

$$\vartheta P_{it} / \vartheta Q_{it} = \gamma_0 + \sum_{z=1}^k \gamma_{iz} Q_{i,t-1} + \sum_{z=1}^k \lambda_{iz} P_{i,t-1} + \mu_{it} \quad (11)$$

Here, ϑ is the 1st differences operator, i shows the cross section unit, and t means time. The causality between the series is shown if P is the cause of Q , and bidirectional cause means both have the causal relation where Q causes P and vice versa.

2.6. Variable Justification and Hypotheses of the Study

However, the first hypothesis (H_1) states that “economic growth has a positive effect on CO₂ emission in the G-3 countries.” The GDPG has a positive impact on EP. Economic growth positively impacts carbon emission and was supported by Mesagan [52]; Arouri et al. [22]; Cheng et al. [60]; Mikayilov et al. [64]; Marques et al. [67]; Bilgili et al. [37]; Anser et al. [70]; and Ridzuan et al. [82]. The second hypothesis (H_2) “renewable energy significantly reduces the CO₂ emission in G-3.” The RENEW reduces CO₂ emissions and was exposed by Qi et al. [58]; Cheng et al. [60]; Hanif [66]; Bilgili et al. [37]; Liu et al. [53]; Spetan [43]; Li and Su [48]; and Esquivias et al. [5]. In the last hypothesis, (H_3) implies that “energy consumption significantly affects CO₂ emission in G-3 countries.” The ENRC increases carbon dioxide emissions and was found by Cheng et al. [60]; Anser et al. [70]; and Stretesky and Lynch [45]. Other studies also find a decrease in carbon emissions from other economic variables related to GDP and consumption [49,82].

3. Results

Table 2 shows the statistical nature of the data of G3 countries through the values of the “mean, median, maximum, minimum, and standard deviation” as well as skewness and kurtosis. However, the mean values for the variables LnCO₂, LnGDPG, LnEnrc, and LnRenew are 18.61, 1.27, 9.52, and 2.67, respectively. At the same time, the median values of the variables LnCO₂, LnGDPG, LnEnrc, and LnRenew are 18.47, 1.40, 9.57, and 2.89, respectively. The standard deviation of the selected panel shows that the SDs of the variables LnCO₂, LnGDPG, LnEnrc, and LnRenew are 0.84, 0.75, 0.56, and 0.66, respectively. However, the minimum and maximum values of all the selected variables were also given, and the descriptive statistics assure that there is no inconsistency in the variables used to estimate the respected econometric model.

Table 2. Results of Descriptive Statistics.

	LNCO ₂	LNBDPG	LNENRC	LNRENEW
Mean	18.61	1.27	9.52	2.67
Median	18.47	1.40	9.57	2.89
Max.	20.02	2.91	10.51	3.56
Min.	17.16	−1.64	8.59	1.54
Std. Dev.	0.84	0.75	0.56	0.66
Skew.	0.31	−1.25	0.28	−0.20
Kurt.	1.83	5.51	1.82	1.43

Source: Author’s estimation.

Table 3 states the results of “Pesaran scaled LM and Pesaran CD” for testing the CSD among the cross-section unit. The test statistics show that the probability value has been rejected for the developed null hypothesis, which states the subsistence of CSD among the panel countries. However, the PP and ADF Fisher Chi-square tests were applied to the data of G-3 countries to check the stationarity of the data.

Table 3. Cross Sectional Dependency Test.

Tests	Statistic	Prob.
Pesaran scaled LM	33.91	0.00
Pesaran CD	9.42	0.00

Source: Author’s estimation.

The outcomes of the unit root tests are presented in Table 4 for G-3 countries. The unit root measurements consider the variable unit root test results regarding trend and intercept. It has been found that LnGDPG is stationary at I (0), which means the variable is stationary at level. The variables LnCO₂, LnRenew, and LnEnrc are stationary at I (1), which means they are stationary at the first difference. Due to the presence of CSD and mixed order

in the data stationery, this case suggests the PMG Panel ARDL approach for estimating the output.

Table 4. Cross Sectional Im, Pesaran, and Shin (CIPS) Panel Unit Root Results.

Variables	Level		First Difference		Decision
	W-Stat	p Value	W-Stat	p Value	
LnCO ₂	−1.63	0.90	−4.39	0	I (1)
LnGDPG	−3.08	0	−284	0	I (0)
LnRenew	7.79	0.25	207.73	0	I (1)
LnEnrc	1.29	0.97	63.95	0	I (1)

Source: Author's estimation.

Table 5 shows the results of the optimal lag selection criterion, where the optimal lag are resolute by the minimum value of the AIC and SC/SIC criterion. However, the optimum lag for the PMG Panel ARDL model is 1.

Table 5. Optimum Lag Length.

Lag	LogL	FPE	AIC	SC	HQ
0.00	−205.18	0.00	6.09	6.25	6.16
1.00	304.16	2.44 *	−7.94 *	−6.97 *	−7.56 *
2.00	321.90	0.00	−7.74	−5.96	−7.03
3.00	338.91	0.00	−7.50	−4.91	−6.48
4.00	366.52	0.00	−7.58	−4.18	−6.23

Source: Author's estimation and * indicates the optimum lag.

Table 6 shows the result of the cointegration test; the test statistics reject the H_0 that “there is no cointegration or long-run association among the variables.” The results of the KAO test declare the “long-run association among the variables.” Table 7 shows the result of the PMG Panel ARDL model with respective coefficients, standard errors, *t*-statistics, and the probability of the variables. In the long run, GDP growth has had a positive impact on CO₂ emissions and has been co-integrated with CO₂ emissions, but the effect is marginal. A 1 percent increase in LnGDPG tends to raise 0.02 percent of CO₂ emissions in G-3 countries. The coefficient of variable LnEnrc is positive and significantly effects on pollution in G-3 countries. The outcomes point out that a 1 percent increase in LnEnrc be inclined to increase 1.39 percent of CO₂ emissions. This result is consistent with the findings of Boutabba [68], who discovered there are long-term and causal interactions between CO₂ and LnEnrc. Renewable energy (LnRenew) consumption significantly decreases environmental pollution; the results showed that a 1 percent increase in LnRenew was able to decrease 0.03 percent of CO₂ emissions in G-3 countries, and this result is statistically significant at the 8% level.

Table 6. KAO Cointegration Test.

Test	<i>t</i> -Statistic	Prob.
ADF	−1.77	0.04

Source: Author's estimation.

Table 7. Long-Term and Short-Term Dynamics through PMG Panel ARDL.

Variables		Coefficient	Std. Error	t-Statistic	Prob.
Dependent Variable: LnCO ₂					
Long run	LNENRC	1.39	0.16	8.80	0.00
	LNNGDPG	0.02	0.05	0.41	0.68
	LNRENEW	−0.03	0.14	−0.24	0.08
	COINTEQ01 (ECT)	−0.17	0.00	−37.22	0.00
Short run	D(LNENRC)	−0.22	0.42	−0.52	0.61
	D(LNNGDPG)	−0.01	0.01	−0.92	0.36
	D(LNRENEW)	−0.33	0.19	−1.75	0.05
	C	0.93	0.09	10.76	0.00

Source: Author's estimation.

The second phase in Table 7 shows the PMG Panel ARDL result for G-3 countries. In the short run, LnGDPG and LnEnrc were negatively associated with CO₂ emissions and LnRenew was also negatively associated with environmental pollution in G-3 countries. GDP growth rate has a negative impact on explaining pollution (CO₂), but the coefficient value is not statistically significant, where a 1 percent increase in LnGDPG reduces 0.01 percent. In the short run, energy consumption (LnEnrc) has no significant impact on CO₂ emissions. Renewable energy (LnRenew) consumption extensively decreases environmental pollution; the results showed that a 1% increase in LnRenew was able to decrease 0.33 percent of CO₂ emissions in G-3 countries. The ECT value demonstrates the speed of adjustment of disequilibrium correction. In Table 7, it is observable that ECT stands at −0.17 with statistically significant results, which imply that the speed of correction of the disequilibrium adjustment is 17 percent (time) to reach a long-term balance.

3.1. Cross Section Short Run Coefficient

3.1.1. Colombia

From Table 8 in Colombia, “the fact that the coefficient of error correction is negative and statistically significant implies that the speed of adjustment to the correction disequilibrium to reach long-term equilibrium is 16%.” Energy consumption (LnEnrc) is negatively allied with emission (CO₂) in the short run (SR) estimations. In the SR, renewable energy (LnRenew) is also negatively allied with CO₂ emissions in Colombia, which is the superior way of producing clean energy and reducing pollution levels. GDP growth rate is positively linked with pollution in Colombia in the SR dynamics, where a one percent increase in GDP growth significantly raises CO₂ emissions (as a proxy for pollution) by 0.01%. Positive associations between pollution and economic growth have been established by Blanco Camargo et al. [83], Laverde-Rojas et al. [84], and Ridzuan et al. [82], among others.

Table 8. Short Run Dynamics of Cross-Section Unit.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Dependent Variable: LnCO ₂				
Colombia				
COINTEQ01 (ECT)	−0.16	0.01	−25.14	0.00
D(LNENRC)	−0.04	0.03	−1.46	0.24
D(LNNGDPG)	0.01	0.00	56.30	0.00
D(LNRENEW)	−0.25	0.01	−39.27	0.00
C	0.89	0.12	7.26	0.01

Table 8. Cont.

Variable	Coefficient	Std. Error	t-Statistic	Prob.
Dependent Variable: LnCO ₂				
Venezuela				
COINTEQ01 (ECT)	−0.17	0.01	−16.80	0.00
D(LNENRC)	−1.01	0.48	−2.10	0.13
D(LNGDPG)	−0.02	0.00	−107.95	0.00
D(LNRENEW)	−0.69	0.05	−13.08	0.00
C	0.81	0.25	3.26	0.05
Mexico				
COINTEQ0 1(ECT)	−0.17	0.01	−30.72	0.00
D(LNENRC)	0.41	0.06	7.13	0.01
D(LNGDPG)	−0.01	0.00	−108.79	0.00
D(LNRENEW)	−0.05	0.00	−46.27	0.00
C	1.10	0.17	6.55	0.01

3.1.2. Venezuela

The coefficient value of ECT in Venezuela is negative and significant and the value shows that the speed of adjustment to the correction disequilibrium to reach long-term equilibrium is 17%. In the short run, energy consumption (LnEnrc) is negatively associated with pollution in Venezuela. GDP growth, as a pollution factor, has no short-term impact on pollution in Venezuela. In the short run, renewable energy (LnRenew) is negatively related with CO₂ emissions in Venezuela, which is the superior method of producing clean energy and lowering pollution levels. A 1% increase in renewable energy can diminish CO₂ emissions (a proxy for pollution) by 0.69%. In Venezuela, Robalino-López et al. [36] and Peyerl et al. [85] revealed a converse relationship between pollution and renewable or clean energy consumption.

3.1.3. Mexico

In Mexico, “the coefficient of error correction term is negative and statistically significant, which implies that the speed of adjustment to the correction disequilibrium to reach long-term equilibrium is 17%.” GDP growth has no effect on pollution in Mexico in the SR as a pollution factor. In the SR, renewable energy consumption is also negatively associated with CO₂ emissions in Mexico, which is a more sustainable way of producing clean energy and reducing environmental degradation. Adding one percent more renewable energy reduces CO₂ emissions (a proxy for pollution) by 0.05 percent. Energy consumption (LnEnrc) is positively associated with pollution in Mexico, where 1% increase in energy consumption significantly raises CO₂ emissions (as a proxy for pollution) by 0.41%. Raihan and Tuspekova [34] have found a positive alliance between pollution and energy utilization in Mexico.

Mexico experienced 3.5 times the increase in per capita energy consumption in the last 50 years, compared with less than 2.5 times in Venezuela and Colombia. Venezuela and Colombia increase the use of renewable energy as a percentage of total energy use, reaching more than 30%. Mexico, by contrast, remains below 10% on the use of renewable energy. The considerable growth of industrial activity in Mexico and the increase in energy consumption was accompanied by a slow transition to cleaner energy, causing a less environmentally friendly path of growth for Mexico compared with Colombia and Venezuela.

The Dumitrescu and Hurlin [86] panel causality in Table 9 shows there is “bidirectional causality (BC)” between energy and pollution. Because of the large amount of energy used in growth and development activities, energy contributes to pollution. There is also BC between variable GDPG and ENRC in G-3 countries. This is the growth and energy nexus,

which is assumed as a precondition of the development of an economy where development demands a large volume of energy. There is no causality involving RENEW and economic GDPG consumption. There is also BC between the variables ENRC and RENEW; in this case, energy consumption should be reduced while renewable energy consumption should be increased.

Table 9. Dumitrescu Hurlin Panel Causality Tests.

Null Hypothesis:	W-Stat.	Zbar-Stat.	Prob.	Decision
LNENRC > LNCO ₂	9.88	10.02	0.00	✓✓
LNCO ₂ > LNENRC	8.27	8.19	0.00	✓✓
LNGDPG > LNCO ₂	1.49	0.47	0.64	✓
LNCO ₂ > LNGDPG	3.10	2.25	0.02	✓
LNRENEW > LNCO ₂	1.70	0.74	0.46	✓
LNCO ₂ > LNRENEW	2.88	2.09	0.04	✓
LNGDPG > LNENRC	2.74	1.86	0.05	✓✓
LNENRC > LNGDPG	3.47	2.66	0.01	✓✓
LNRENEW > LNENRC	4.84	4.30	0.00	✓✓
LNENRC > LNRENEW	4.43	3.84	0.00	✓✓
LNRENEW > LNGDPG	1.63	0.63	0.53	≠
LNGDPG > LNRENEW	0.24	−0.90	0.37	≠

Note: the sign ">" means "does not homogeneously cause" between the variables. Symbols: "✓✓", "define the bidirectional causality", "✓", "define the unidirectional" and "≠", "define the no causality".

4. Discussion

However, hypothesis testing and discussion based on coefficients of long-run dynamics state that, as the findings show, long-run GDPG has a positive impact on pollution (CO₂); this result has failed to reject the first hypothesis. The economic growth in the three Latin American countries (G-3) is associated with economic growth and with increased CO₂ emissions, indicating that the growth trajectory is on an unsustainable path. Lee [87] discovered similar findings in the European Union and Yang et al. [88] discovered similar results in the SERB countries, although the negative impact from economic growth on environmental quality in SERB follows the inverted U-shaped. The findings also demonstrate that "long-run energy consumption has a positive impact on carbon emissions" and that result has failed to reject the second hypothesis. Similar kinds of findings were found by Nawas et al. [18] and Musah et al. [89] in North Africa. The G-3 countries have relied on high levels of energy consumption to support the country's growth, suggesting that the energy strategy needs to rethink more sustainable means of generating, distributing, and consuming energy. Industrial activity, transportation, and private energy demand require better technologies to reduce energy consumption and lower CO₂ emissions. Improvements in innovation can enhance economic growth in a more sustainable manner [90].

The third hypothesis was that the variable RENEW reduces CO₂ emissions and this study discovered a negative long-run estimation coefficient for the impact of renewable energy on pollution. This type of finding was founded in G-7 countries by Hao et al. [91] and Li and Haneklaus [92]. The G-3 could capitalize on greater use of renewable energy to reduce CO₂ emissions and improve the environment. Colombia and Venezuela have increased the use of renewable energy at a higher rate than Mexico. Offering incentives for both the public and private sectors to use more renewable energy could generate a substantial increase in the quality of the environment in G-3 countries. Replacing dirty energy with cleaner energy can be considered an energy policy priority.

Due to the large volume of energy consumed in the G-3, environmental pollution largely increases in the long run. Although the variable of GDPG has no significant impact on accelerating pollution in the short run, it has a positive association in the long run. The panel causality test also indicates a significant nexus between GDP and CO₂. The significance of using RENEW has been extensively shown in the estimation process, where it has a significant role in reducing emissions in the G-3 countries in the short and long

run. As a strategy, the G-3 countries need to promote lower energy consumption, greater use of renewable energy, and an energy transition where economic activity is less energy intensive. Improving efficiency in energy uses, reducing electricity losses, and promoting more advanced technologies that consume less energy can help improve environmental quality in the G-3.

5. Conclusions

Energy supply is increasing on a regular basis in order to strengthen the global economy; however, energy use and emissions are also increasing in the same direction, jeopardizing the planet. The primary goal of this paper was to learn about the effects of GDPG and energy consumption on environmental pollution (EP) in the G-3 countries (Colombia, Mexico, and Venezuela). Furthermore, the significance of renewable energy to the reduction purpose of EP was investigated, as were the long- and short-run impacts of the selected variables on pollution in the G-3 countries. Finally, a causality test was used to consider the causal association between the variables that were chosen. For this research, data were collected from the “World Development Indicator (2022) and the International Energy Statistics (2022)” for the G-3 countries. A balanced panel of data was collected from 1970 to 2020. It was found that the data on GDP growth was stationary at I (0) and that pollution (CO₂ emissions), energy consumption (ENRC), and renewable energy consumption (RENEW) were stationary at I (1). This mixed-order integration and the presence of CSD suggested the PMG Panel ARDL approach. The result of the optimal lag selection is 1 in the selected panel.

In the long run, GDP growth has a positive influence on pollution (CO₂ emissions) and is co-integrated with CO₂ emissions, but the effect is not significant. In the G-3 countries, a 1 percent increase in GDPG tends to increase pollution by 0.02 percent. In G-3 countries, the coefficient of variable energy consumption is co-integrated with pollution, but the effect is not significant. In the G-3 countries, a 1 percent increase in GDPG tends to increase pollution by 0.02 percent. The coefficient of variable ENRC is positive, which has a significant impact on CO₂ emissions. According to the findings, a one percent increase in ENRC tends to increase CO₂ emissions by 1.39 percent. The use of renewable energies (RENEW) significantly reduces environmental pollution; a one percent increase in RENEW can reduce 0.03 percent of CO₂ emissions. The ECT value demonstrates the speed of adjustment of disequilibrium correction. ECT stands at −0.17 with statistically significant results, which imply that the speed of correction of the disequilibrium adjustment is 17 percent to reach a long-term balance.

We suggest that reassuring environmentally friendly energy utilization in G-3 countries can help reduce environmental degradation in the G-3. Policymakers could consider the utilization of clean, environmentally friendly energy to contribute to combating worldwide climate change by decreasing carbon dioxide discharges. The G-3 ought to continue to expand the portion of sustainable power while diminishing the portion of non-renewable energy (NRC) for lower levels of emissions. Since decreases in NRC do not degrade the G-3's GDPG, approaches to reduce NRC utilization can be executed without affecting GDPG. Considering that nations can deliver energy from non-renewable sources at a lower cost than from renewable sources, the G-3 ought to help R & D to make the development of energy from sustainable sources somewhat less expensive. However, a tiny limitation of this study is the missing data in several years. Further studies may be conducted in similar issues in different panel groups.

Appropriate policies are required to reduce environmental pollution. Economic growth and energy consumption in G-3 countries should be given special consideration because they are positively allied with the EP in the long run. These two variables demonstrated a critical check to halt CO₂ emissions. Furthermore, renewable energy consumption should rise as it reduces pollution in the G-3 countries. In this perspective, the use of renewable energy can take a significant role in reducing pollution (CO₂ emissions); therefore, adequate policy support for technological innovation may help to accelerate the transition

towards cleaner energies. Mexico appears as having a more critical environmental situation, compared with Colombia and Venezuela, as energy consumption and economic growth are positively driving CO₂ emissions. Colombia and Venezuela have expanded the use of renewable energy more rapidly than Mexico and have lower energy intensity, suggesting they have a more environmentally friendly economic path. A focus on the use of renewable energy, solar energy, and biomass energy could provide an energy mix to accelerate the shift to cleaner energies. Research and development for sustainable energy should be expanded and as much renewable energy as possible should be included in the overall energy structure. Finally, green technology and clean energy should be prioritized over fossil fuel consumption.

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